

Claims

1. A drive circuit (20a,20b) for an injector arrangement having at least one injector (12a,12b),
5 the drive circuit comprising:
 first charge storage means (C2) for operative connection with one of the at least one
 injectors (12a,12b) during a discharging phase so as to permit a discharge current to flow
 therethrough, thereby to initiate an injection event;
 second charge storage means (C1) for operative connection with the at least one
10 injector (12a,12b) during a charging phase so as to cause a charge current to flow
 therethrough, thereby to terminate the injection event;
 switch means (Q1,Q2) for controlling whether the first charge storage means (C2) is
 operably connected to the at least one injector or whether the second charge storage means
 (C1) is operably connected to the at least one injector;
15 a first voltage rail (V_0, V_{supply}) at a first voltage level;
 a second voltage rail (V_1) at a second voltage level higher than the first voltage level;
 a voltage supply means (22,36); and
 regeneration switch means (Q5,Q2, L1) operable at the end of the charging phase to
 transfer charge from the voltage supply means to at least the second charge storage means via
20 an energy storage device (L1), prior to a subsequent discharging phase.
2. The drive circuit (20a,20b) as claimed in claim 1, wherein the first charge storage means
(C2) is connected across the first voltage rail (V_0, V_{supply}) and ground.
- 25 3. The drive circuit (20a,20b) as claimed in claim 1 or claim 2, wherein the second charge
storage means (C1) is connected across the first (V_0, V_{supply}) and second (V_1) voltage rails.
4. The drive circuit (20a,20b) as claimed in any preceding claim, further comprising a switch
means including a first switch (Q1) operable to close to activate the charging phase, and a
30 second switch (Q2) operable to close to activate the discharging phase.

5. The drive circuit (20a) as claimed in any preceding claim, wherein the regeneration switch means (Q5,Q2,L1) is operable at the end of the charging phase to transfer charge from the voltage supply means (22) to the first charge storage means (C2) and the second charge storage means (C1).

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6. The drive circuit (20b) as claimed in any of claims 1 to 4, wherein the regeneration switch means (Q5,Q2,L1) is operable at the end of the charging phase to transfer charge from the voltage supply means to the first charge storage means (C2), and from the first charge storage means (C2) to the second charge storage means (C1) via the energy storage device (L1).

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7. The drive circuit (20a) as claimed in claim 5, wherein the regeneration switch means (Q5,Q2,L1) is operable to transfer charge from the voltage supply means (22) to the first (C2) and second (C1) charge storage means in response to the operation of the second switch (Q2) during the regeneration phase.

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8. The drive circuit (20b) as claimed in claim 6, wherein the regeneration switch means (Q5,Q2,L1) is operable to transfer charge from the voltage supply means (22,36) to the first charge storage means (C2) in response to the operation of the second switch (Q2) during the regeneration phase.

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9. The drive circuit (20a,20b) as claimed in any preceding claim, wherein the first (C2) and second (C1) charge storage means comprise capacitors.

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10. The drive circuit (20a,20b) as claimed in any preceding claim, further comprising first (12a) and second (12b) injectors which are arranged in parallel and operatively connected to the switch means (Q1,Q2), the regeneration switch means (Q5,Q2,L1), and a further switch means (Q3,Q4) for controlling independent selection of the first (12a) or second (12b) injector to permit a discharge current to be supplied to the selected injector (12a,12b) during a discharging phase so as to initiate an injection event.

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11. The drive circuit (20a,20b) as claimed in claim 10, wherein the drive circuit is substantially configured as a half H-bridge circuit having a middle circuit branch (32), with the first (12a) and second (12b) injectors being arranged in parallel in the middle circuit branch.

5 12. The drive circuit (20a,20b) as claimed in claim 10 or claim 11, further comprising voltage sensing means for sensing the voltage across each injector (12a,12b), and control means for receiving a signal indicative of the sensed voltage.

10 13. The drive circuit (20a,20b) as claimed in claim 12, wherein the control means is arranged to provide a terminate control signal to the further switch means (Q3,Q4) to terminate the charging phase of the selected injector once a predetermined charge threshold voltage (V_{CHARGE}) is sensed.

15 14. The drive circuit (20a,20b) as claimed in claim 13, wherein the control means is further arranged to provide an initiate signal to the switch means (Q1,Q2) to initiate the charging phase of the selected injector.

20 15. The drive circuit (20a,20b) as claimed in claim 13 or claim 14, wherein the control means is further arranged to provide an initiate signal to the regeneration switch means (Q5,Q2,L1) to initiate the regeneration phase, and to provide a termination signal to the regeneration switch means to terminate the regeneration phase.

25 16. The drive circuit (20a,20b) as claimed in claim 14, wherein the control means is further arranged to provide a terminate control signal to the further switch means (Q3,Q4) to terminate the discharging phase of the selected injector once a predetermined discharge threshold voltage ($V_{\text{DISCHARGE}}$) is sensed.

30 17. The drive circuit (20a,20b) as claimed in claim 16, wherein the control means is further arranged to provide an initiate control signal to the switch means (Q1,Q2) to initiate the discharging phase of the selected injector.

18. The drive circuit (20a,20b) as claimed in any of claims 12 to 17, wherein the control means is arranged to provide a pulse width modulated signal to alternately provide enable and disable signals to the switch means (Q2) during the regeneration phase, thereby to transfer energy to and from the energy storage device (L1).

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19. The drive circuit (20a,20b) as claimed in any preceding claim, wherein the at least one injector (12a,12b) comprises a piezoelectric actuator.

20. A control method for an injector arrangement having at least one injector (12a,12b), the method comprising:

10 operably connecting a first charge storage means (C2) to one of the at least one injectors during a discharging phase so as to cause a discharge current to flow therethrough, thereby to initiate an injection event;

15 operably connecting a second charge storage means (C1) with the at least one injector during a charging phase so as to cause a charge current to flow therethrough, thereby to terminate the injection event;

20 activating a regeneration switch means (Q5,Q2) at the end of the charging phase to initiate a regeneration phase wherein charge is transferred from a voltage supply means (22,36) to an energy storage device (L1), and transferred from the energy storage device (L1) to at least the second charge storage means (C1) prior to the subsequent discharging phase; and

deactivating the regeneration switch means to terminate the regeneration phase.

21. The control method as claimed in claim 20, wherein during the activating step charge is transferred from the voltage supply means (22) to the energy storage device (L1), and
25 subsequently transferred from the energy storage device (L1) to the first (C2) and second (C1) charge storage means.

22. The control method as claimed in claim 20, wherein during the activating step charge is transferred from the voltage supply means (22) to the first charge storage means (C2), and
30 subsequently transferred from the first charge storage means (C2) to the energy storage device (L1) for transfer to the second charge storage means (C1).

23. The control method as claimed in any of claims 20 to 22, wherein the steps of transferring charge to and from the energy storage device (L1) are carried out periodically.

5 24. The control method as claimed in claim 23, wherein the steps of transferring charge to and from the energy storage device (L1) are carried out under the control of a pulse-width modulated signal.

10 25. The control method as claimed in claim 24, including the further step of varying the duty cycle of the pulse width modulated signal.

15 26. The control method as claimed in any of claims 20 to 25, including the further step of controlling whether the first (C2) or second (C1) charge storage means is operably connected to the at least one injector (12a,12b).

27. The control method as claimed in any of claims 20 to 26, including the further step of providing a regeneration initiate signal to activate the regeneration switch means (Q5,Q2) so as to initiate the regeneration phase.

20 28. The control method as claimed in claim 27, including the further step of providing a regeneration terminate signal to deactivate the regeneration switch means (Q5,Q2) so as to terminate the regeneration phase.

25 29. The control method as claimed in claim 27, wherein the regeneration initiate signal is provided after a predetermined number of injection events.